Distributed Energy Neural Network Integration System (DENNIS) Quarterly Review

Orion Engineering Corporation

By:

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at the July Quarterly Review Meeting

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How Can Distributed Generation Get Full-Value Pricing?

- Avoided cost and net metering models are not viable for providing the first cost recovery rates needed to make distributed resources economical for household and small commercial applications.
- A solution to economically integrate distributed resources onto grid is needed. This solution should capture the full-value of the distributed resource.
- Solution will need to be adaptable, knowing when to sell and when to store energy (decoupling essential).
- Solution will also need capacity to aggregate small blocks of power production into blocks large enough to make and place bids to the ISO.

Distributed Energy Neural Network Integration System (DENNIS)

- Distributed generation and storage systems need an adaptive mechanism that allows for the resources to predict the site specific energy generation capacity and power consumption.
- DENNIS is optimization system that uses neural networks and fuzzy logic to determine where, when and which distributed generation resources are utilized.
- Solution predicts and meets demand of a particular user instead of curtailing that user's demand.
- Our system will be capable of optimizing to a single user or to a larger group of users. Year II and III have plans to expand this aspect of development for "neighborhood controller".

How Does DENNIS Work?

- A Neural Pattern Database monitors and learns load, weather, price and available power data streams
- Incoming signals are compared with patterns stored in Neural Pattern Database to select appropriate operating conditions
- Optimization algorithm selects control strategy for power storage, power export/import and generation dispatch

Program Goals (Overall)

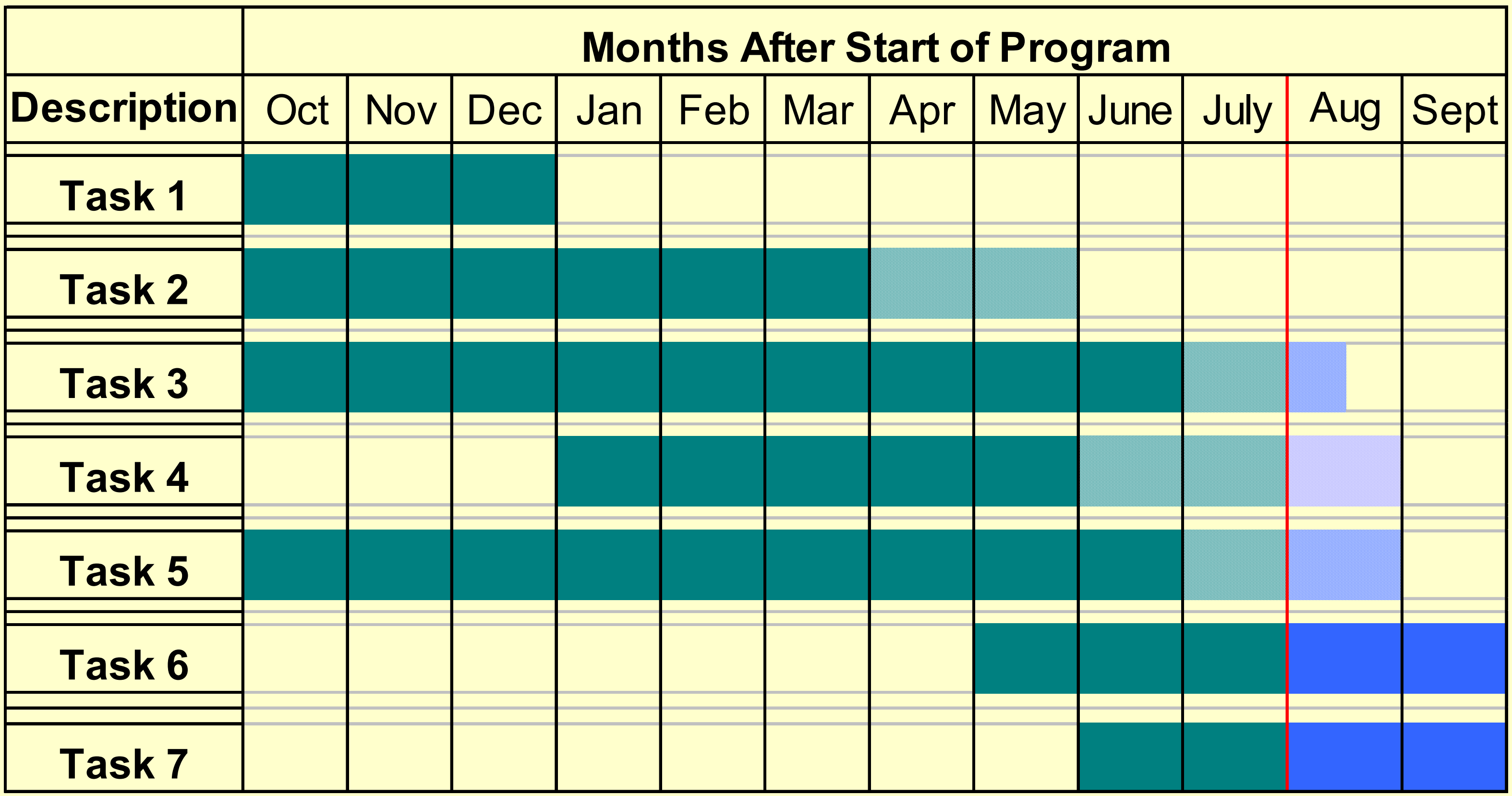
- Prototype, test and evaluate the system utilizing the facilities at the University of Massachusetts Lowell (UML) Center for Energy Conversion (CEC).
- Develop an economic model/analysis of the potential impact of our method for aggregating and managing distributed power.
- Deploy units to DER sites in two phases. First phase provides geographic dispersal during debugging and analysis. Second phase will be a beta product release.
- Establish industrial contacts and relationships to allow effective transfer of product into residential and business sectors.
- Inform and demonstrate to the electric power community the potential of a new business in generation communities.

Year One Program Tasks

Task 1 – Data Reduction and Analysis (Completed)
Task 2 – Power Electronics (Completed)
Task 3 – Fuel Cell Characterization and Integration (Underway)
Task 4 – Power Quality Study (Underway)
Task 5 – Pattern Database & Pattern Recognition (Underway)
Task 6 – Control Law Generator (Underway)
Task 7 – Preliminary Economic Analysis and Market Assessment (Underway)

GOALS – Make infrastructure investments, develop neural network systems, and validate savings potentials.

Year One Program Schedule



Task 1 – Data Reduction and Analysis

- UML Facility data for last 3 years input into database (partial for 2 other years). Data includes: insolation, wind speed, system generation via voltage and current.
- Data utilized extensively in Tasks 5 and 7
- Weather data from local airports used to augment facility weather data and fill in gaps in UML weather data. This data includes wet/dry bulb temperature, wind direction & character, barometric pressure, sky cover, visibility and precipitation.
- ISO data has also been added for hourly clearing prices, and natural gas prices has been added from EIA reports.

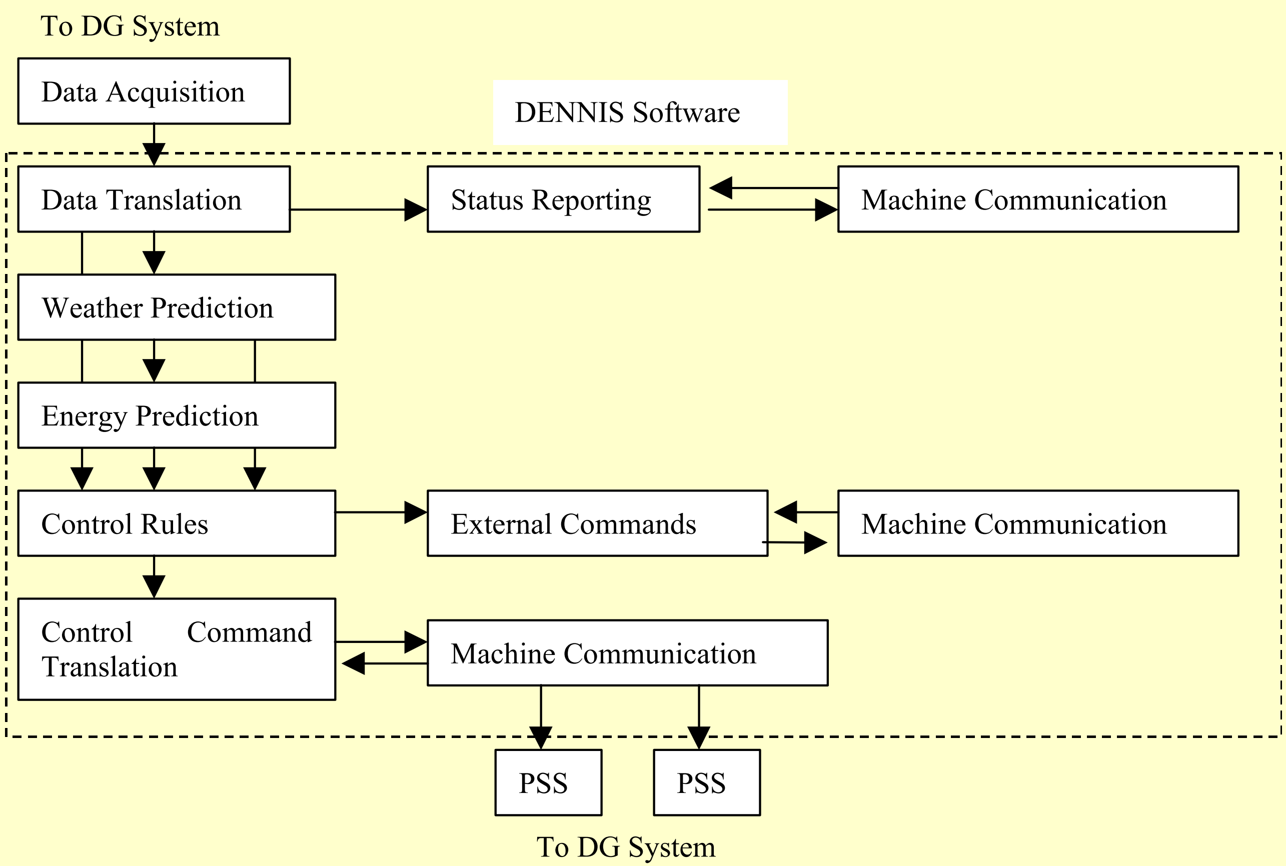
100% Complete

Task 2 - Power Electronics

- Current inverter system upgraded to allow for computer control of load switching.
- Machine Communications Modules (MCMs) and Status Reporting Modules (SRMs) built.

100% Complete

Task 2 - Power Electronics



Task 2 - Load Uncoupling Analysis

- Uncoupling Analysis (Three scenarios):

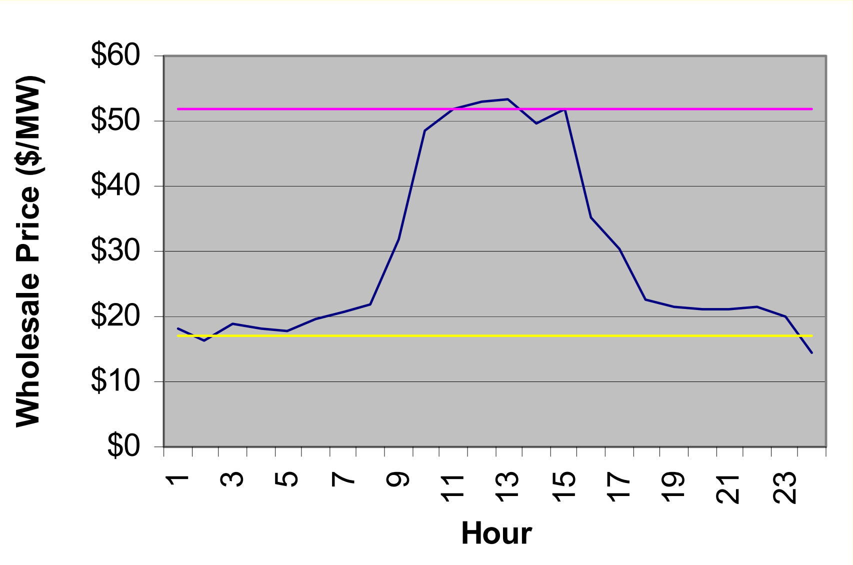
Scenario 1: UPS, Reliability

	Loss of Supply (Minutes)								
	0.1	1	10	100	1,000	10,000			
	Probability of Occurrence								
	0.833	0.083	0.050	0.025	0.008	0.001			
Available Storage (Minutes)							Expected Benefit	Storage Cost	Benefit/Cost Ratio
10	$100	$102	$117	$1,000	$1,000	$1,000	$132	$100	$1.32
100	$100	$102	$117	$267	$10,000	$10,000	$196	$100	$1.96
1000	$100	$102	$117	$267	$1,767	$100,000	$202	$200	$1.01
10000	$100	$102	$117	$267	$1,767	$16,767	$133	$1,700	$0.08

Task 2 - Load Uncoupling Analysis

- Uncoupling Analysis (Three scenarios):

<u>Scenario 2: Real Time Pricing</u>



Discharge Rate	Power	Energy Capacity	Price Differential	Net Revenue
1	4800	4800	$38.90	$0.19
2	3029	6058	$37.75	$0.23
3	2170	6509	$36.63	$0.24
4	1498	5990	$35.98	$0.22
5	1085	5424	$35.04	$0.19
6	672	4032	$34.15	$0.14
7	413	2890	$31.46	$0.09
8	298	2381	$28.98	$0.07
9	192	1728	$26.84	$0.05
10	96	960	$24.32	$0.02

Task 2 - Load Uncoupling Analysis

- Uncoupling Analysis (Three scenarios):

  <u>Scenario 3: Peak Shaving, Time-of-Use Offset</u>

$$\mathrm{MAX}\ \left[\sum_H (G_H - L_H)\right] - \mathrm{MIN}\ \left[\sum_H (G_H - L_H)\right]$$

H	is the hour of the day
G_H	is the expected generation for that hour
L_H	is the expected load for that hour

If the storage only needs to capture excess generation the storage capacity in kWh is given by:

$$\sum_H (G_H - L_H) \text{ for all } (G_H - L_H) > 0$$

Task 3 - Fuel Cell Characterization and Integration

- Hydrogen PEM Cell - Temporary unit received recently
- Problem - Fundamental lack hydrogen infrastructure and knowledge of hydrogen systems (safety)
- Environmental Health and Safety had concerns about having large quantities of hydrogen in building. This problem has been resolved.

45% Complete

Task 3 - Fuel Cell Characterization and Integration

- $250W_e$ PEM
- DC Output
- Hydrogen fueled

<u>Challenges</u>:

- Hydrogen safety concerns and infrastructure
- Completing sales and delivery transaction

Task 3 - Fuel Cell Characterization and Integration

- Safety procedures and SOPs (Completed)
- Fuel cell DAQ system (Completed)
- Fuel cell DC/DC converter (Completed)
- Fuel cell installation and commissioning (Completed by 7/31)
- Theoretical fuzzy model (Completed by 7/31)
- Fuzzy model verification plan (Completed by 7/31)
- Fuzzy model parameter measurement (Completed by 8/15)
- Fuzzy model verification (Completed by 8/15)

Task 4 – Power Quality Study

- Characterize harmonic content of facility. Measure total harmonic distortion (THD) from individual resources and from the utility interconnect (IEEE 519 and P1547)
  - Individual DC/DC converters, rectifiers, and maximum power point tracker (Completed by 8/15)
  - Inverter output under different loadings (Test plan developed. Testing completed by 8/31)
  - Fuel cell DC/DC converter (Completed by 8/31)

40% Complete

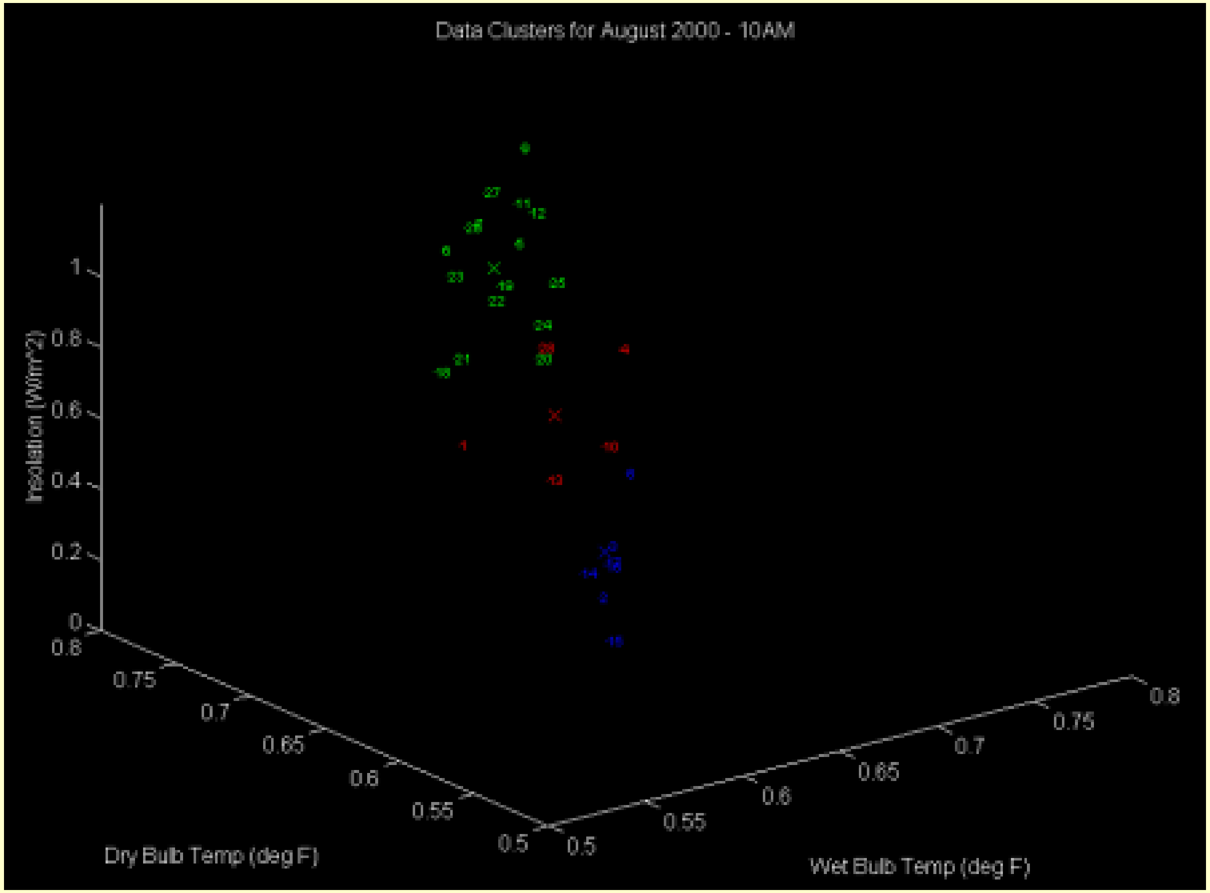
Task 5 – Pattern Database Development

- Correlate weather data parameters with day types to determine best set of input signals (Completed)
- Manually separate day types into bins using input parameters (Completed)
- Build simple perceptron-type network to test general ability to automatically distinguish day types (80% completed)
- Code ART neural network using input signal basis from previous 3 steps (Completed by 8/15)
- Test stability and plasticity of ART network, revise as necessary to assure flexible automatic learning (Completed by 8/31)

70% Complete

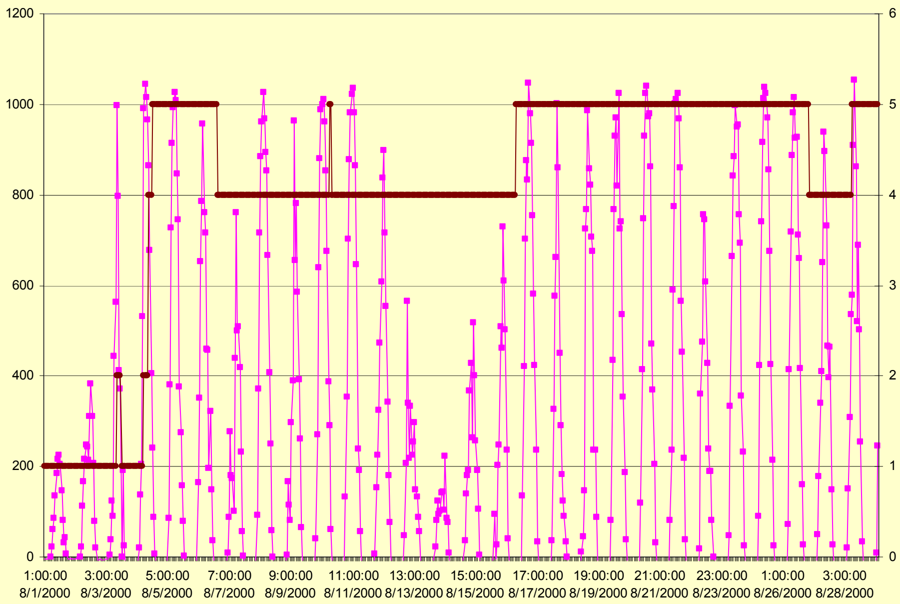
Task 5 – Pattern Database Development

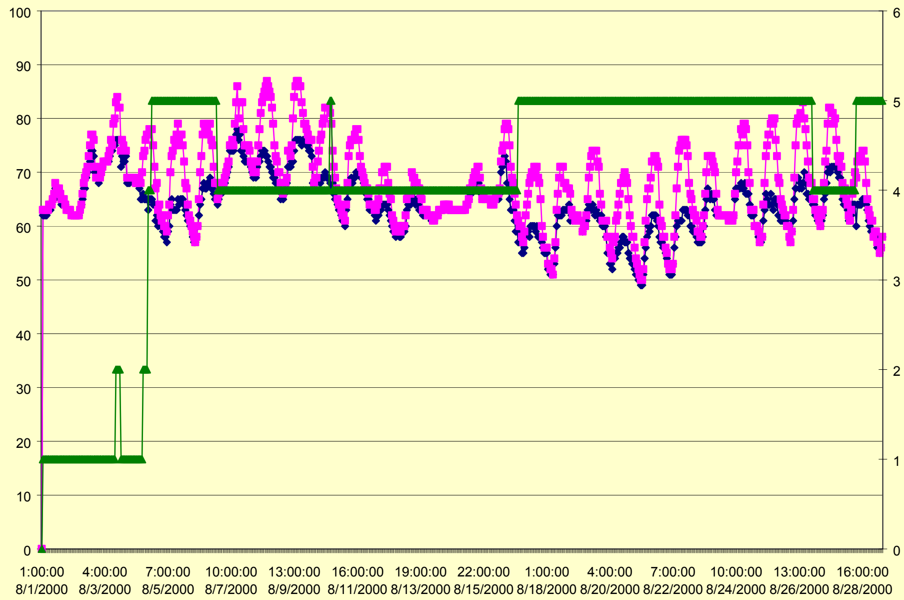
Manually separate day types into bins using input parameters



Task 5 – Pattern Database Development

Build simple perceptron-type network to test general ability to automatically distinguish day types





1=Rainy 2=Hazy 3=Hazy/Partly Sunny to Sunny

4=Partly Sunny 5=Sunny

Task 6 – Control Law Generator

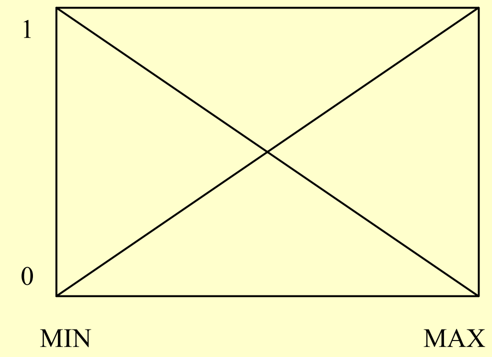
- Identify a set of possible fuzzy constraints based on input sets for available generation, load, and demand. Some of these constraints will be hardware specific and would be analogous to device drivers on a PC. (Completed by 9/7)
- Graph constraints to visualize the constrained region and nature of the problem to be optimized (Completed by 9/7)
- Design perceptron neural network to map inputs to desired optimal output based on graphical solution from step 2 (Completed by 9/15)
- Generalize the algorithm for finding the optimal operating point within the fuzzy constraint structure (Completed by 9/15)
- Move fuzzy constraint boundaries to shift optimal operating point and measure change in cost function (Completed by 9/15)

50% Complete

Task 6 – Control Law Generator

- Constraint rules developed:
  - Internal/External Pricing Mechanism based on Load, Demand and Available Generation
  - Storage Sizing and Allocation

Future Load	Future Price	Future Generation	Storage Capacity Required
H	H	L	H
H	H	H	M
H	L	L	M
H	L	H	M
L	H	L	M
L	H	H	M
L	L	L	M
L	L	H	L



Task 7 – Preliminary Economic Analysis and Market Assessment

- Evaluate effectiveness of a DENNIS controller running residential DG with single connection to the grid. (Completed 9/31)
- Develop our relationship with building automation technology companies to provide a distribution infrastructure for DENNIS to be installed at commercial early adopter sites. (Ongoing)
- Pursue a broader market impact with the Zero Net Energy Alliance of Lowell (Z_NEAL) in Lowell, Massachusetts and are pursuing development of a distributed generation education facility for the state of Massachusetts at the University of Massachusetts Lowell (Ongoing)

30% Complete

Project Summary

At the end of Year One, the following activities will be completed:

- Facilities upgrades at UMLCEC
- Development of the neural networks
- Fuel Cell logic model and characterization
- Power quality studies of facilities and equipment
- Economic models demonstrating that DENNIS is a cost effective solution for distributed generation systems
- Market segmentation and commercialization planning

No issues are currently affecting our ability to deliver the schedule and scope of Year One or the Option Years